ILANCE Student Fest

Exploring the Reconstruction of Inclined Extensive Air Showers for GRAND Project

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Under the supervision of Olivier Martineau, Takashi Sako

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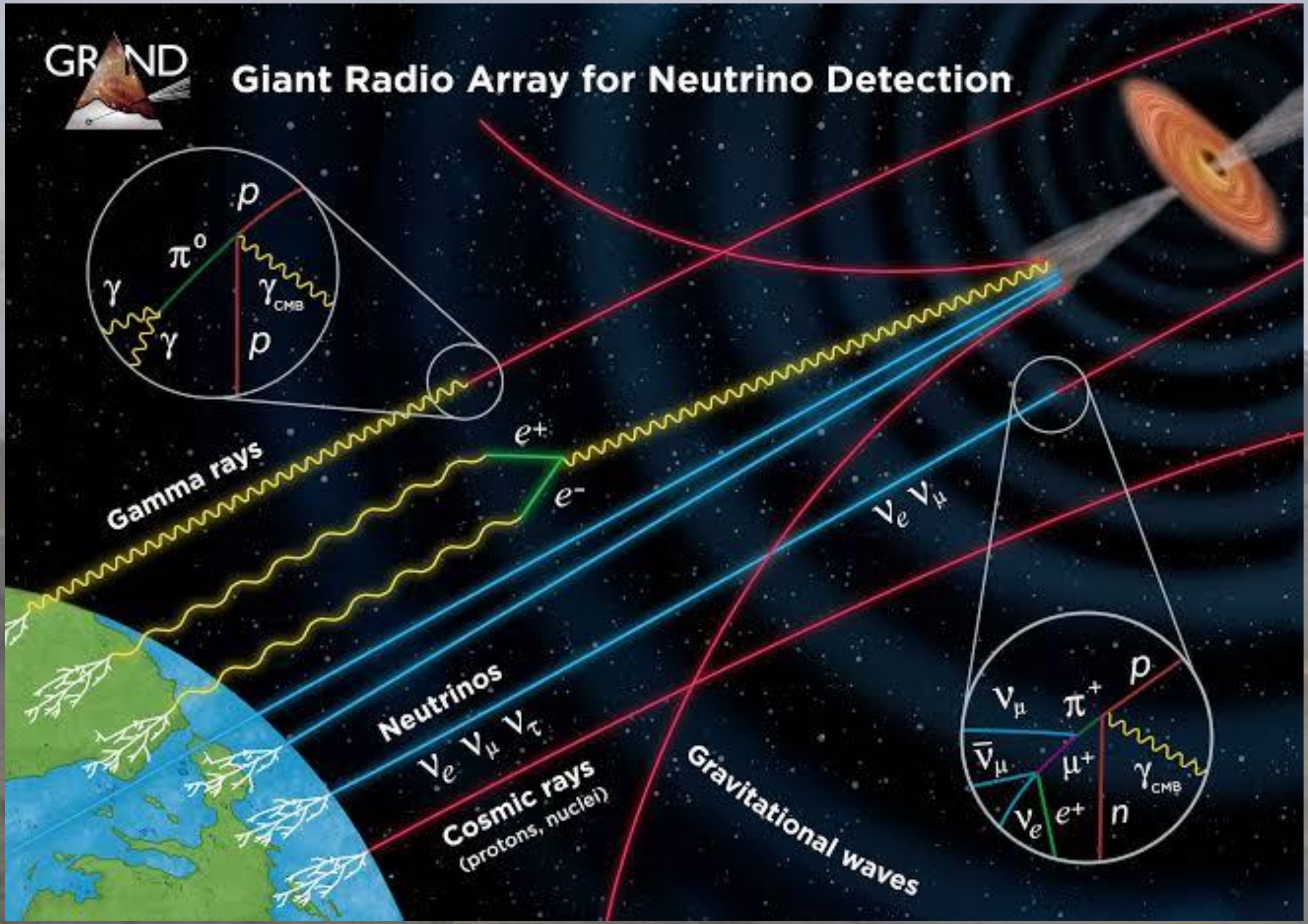
Context – The multi messenger era

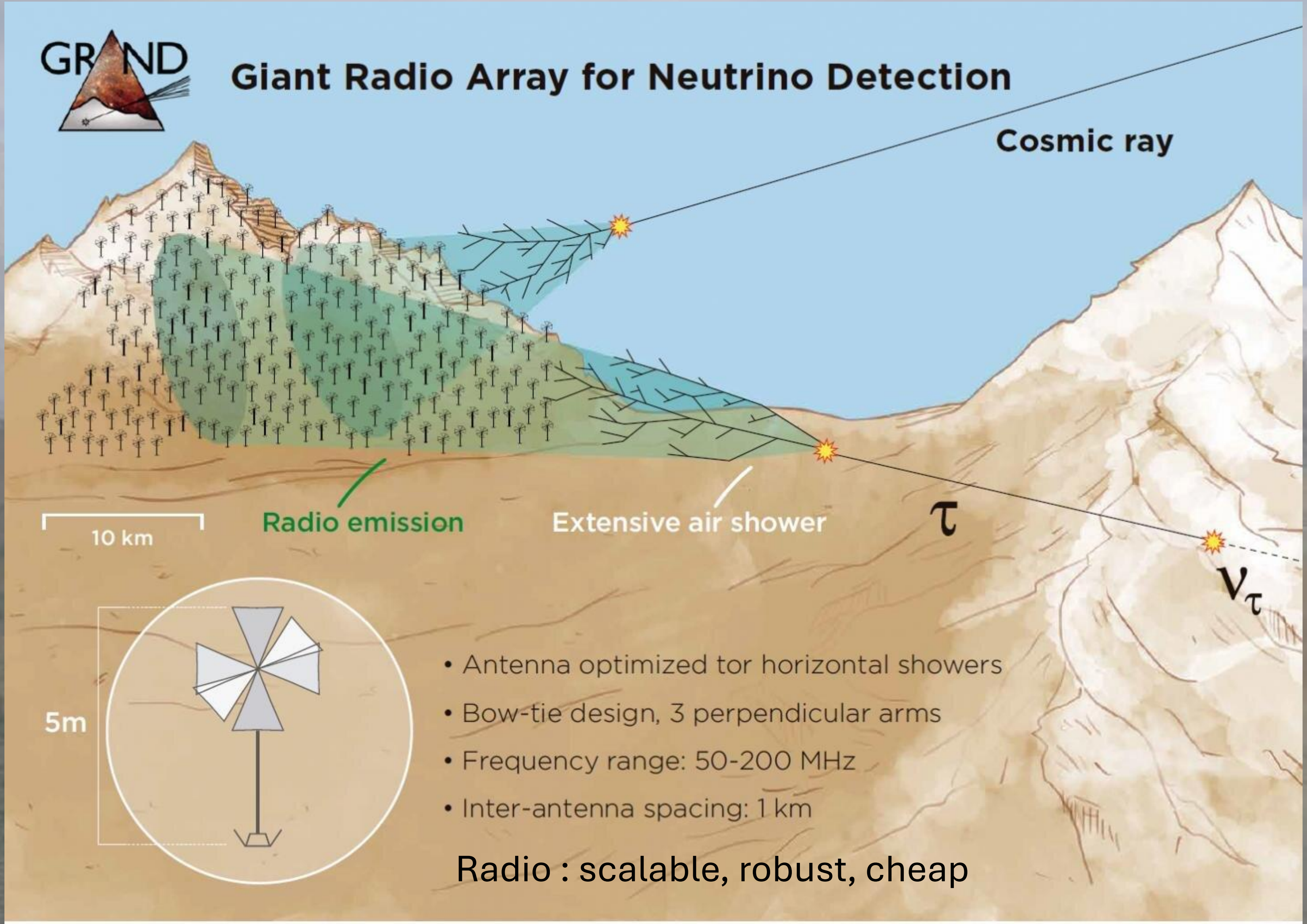


Study violent sources with different messengers.

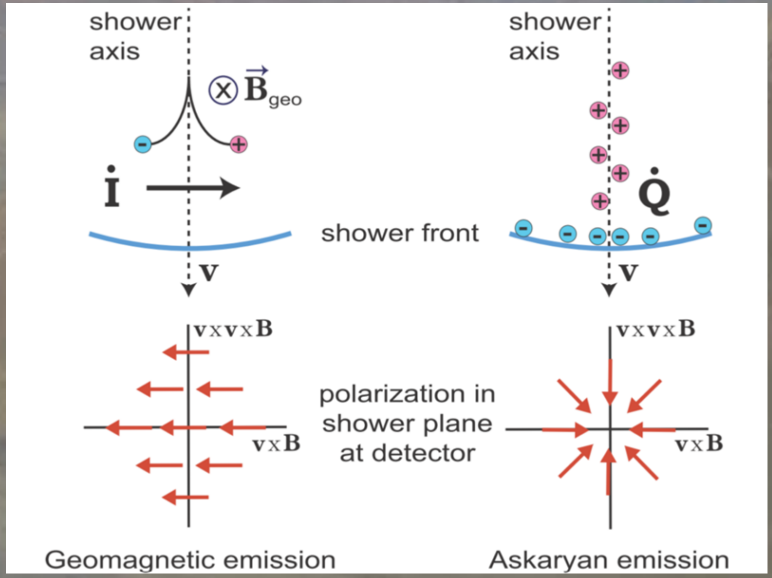
KM3-230213A event : 120 PeV muon stemming from neutrino. Origin ?

→ **More experiments needed !**

Context – Very inclined extensive air showers



Goal with GRANDProto300 : validate autonomous radio detection, for CRs of energy $10^{17} - 10^{18} eV$

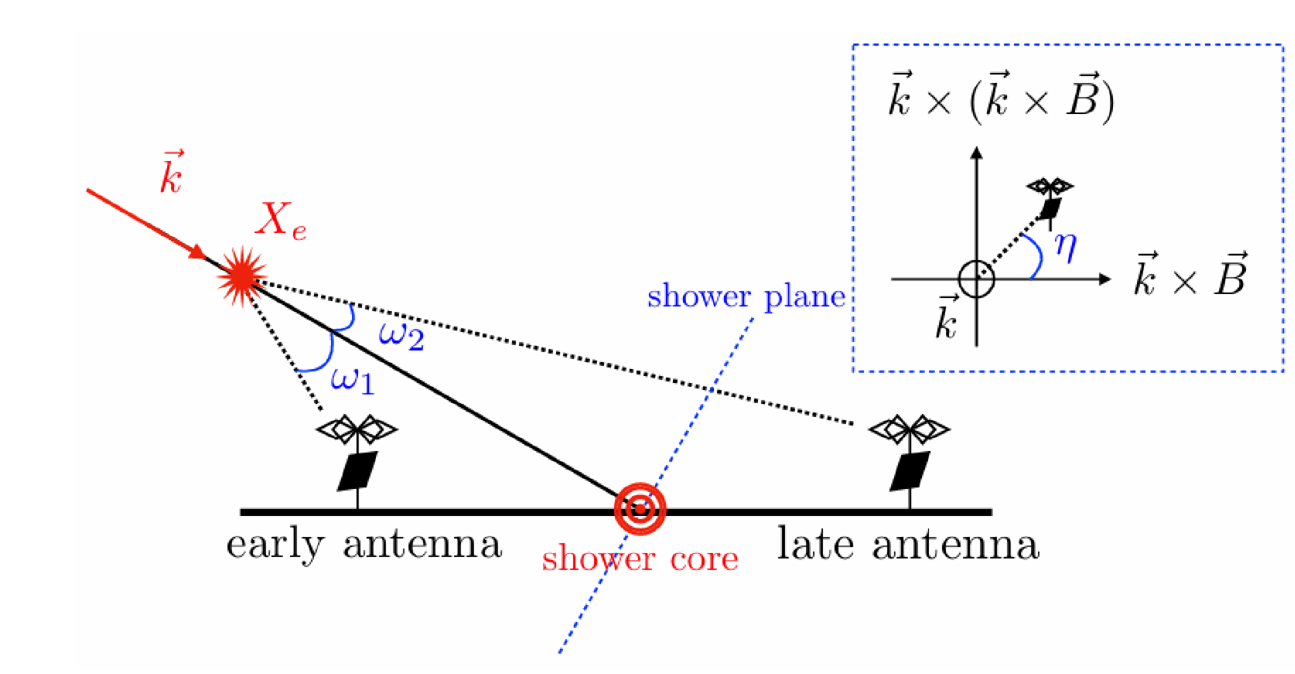


Work – Goal

Reconstruction of inclined air showers (zenith > 60°) :

- Direction of origin
- Energy
- Nature of primary

Coordinate system : (ω, η)



Work – Reconstruction method

STEP 1 : Plane Wave Reconstruction

→Reference direction for the shower origin (θ_0, ϕ_0)

STEP 2 : Spherical Wave Reconstruction

→Initial shower axis with emission point X_e and direction (θ_0, ϕ_0)

STEP 3 : Angular Distribution Function (ADF) fit

→ Final values for $(\theta_{recons}, \phi_{recons})$

Work – ADF method

Four free parameters adjusted : $\theta, \phi, A, \delta\omega$
Emission point (x_e, y_e, z_e) remains fixed

$$R_{\theta,\phi} = \sum_{i=1}^{N_{\text{antennas}}} \left[A_i - f_i^{\text{ADF}}(A, \theta, \phi, \delta\omega; x_e, y_e, z_e)\right]^2$$

$$f^{\text{ADF}}(\omega, \eta, \alpha, l; A, \delta\omega) = \frac{A}{l} f^{\text{Geom}}(\alpha, \eta, G_A) f^{\text{Cherenkov}}(\omega; \delta\omega)$$

$$f^{\text{Geom}}(\alpha, \eta, G_A) = 1 + G_A \frac{\cos(\eta)}{\sin(\alpha)}$$

$$f^{\text{Cherenkov}}(\omega, \delta\omega) = \frac{1}{1 + 4\left[\frac{(\tan(\omega)/\tan(\omega_c))^2 - 1}{\delta\omega}\right]^2}$$

(ω, η) : angular coordinates of the antennas
α : geomagnetic angle
l : longitudinal propagation distance
G_A : geomagnetic asymmetry strength
ω_c : Cherenkov angle
A : scaling factor
$\delta\omega$: width of the Cherenkov cone

arXiv:2504.18257

Work – ADF method

Four free parameters adjusted : $\theta, \phi, A, \delta\omega$
Emission point (x_e, y_e, z_e) remains fixed

$$R_{\theta,\phi} = \sum_{i=1}^{N_{\text{antennas}}} \left[A_i - f_i^{\text{ADF}}(A, \theta, \phi, \delta\omega; x_e, y_e, z_e)\right]^2$$

Works with electric field data...
...Doable with voltage data directly ?

arXiv:2504.18257

Work - Workstream

1. Validate ADF pipeline on old simulations DC2Training ZHAireS
2. Apply ADF to new simulations DC2RF2Alpha
3. Adapt ADF to voltage data directly
4. Perform energy reconstruction on cosmic candidates

Work – Performance comparison

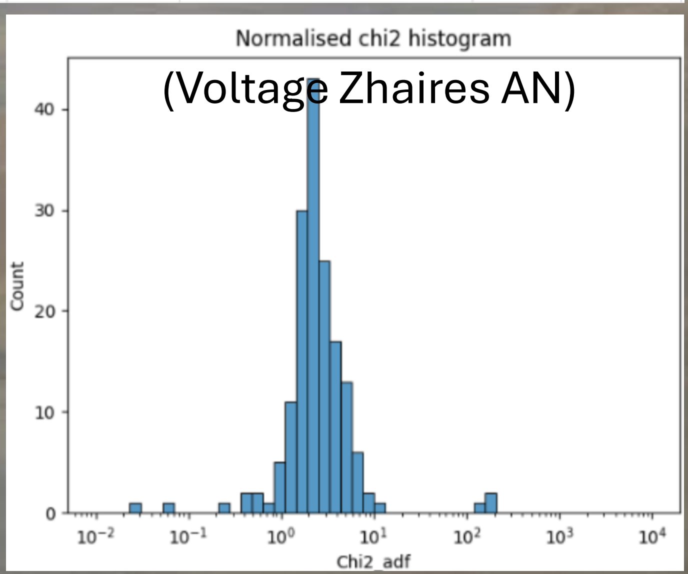
$$\cos(\psi) = \cos(\theta_{rec})\cos(\theta_{true}) + \cos(\phi_{rec} - \phi_{true})\sin(\theta_{true})\sin(\theta_{rec})$$

Cuts	Efield Zhaires		Voltage Zhaires NJ		Voltage Zhaires AN		Voltage Zhaires AN (with uncertainties)	
	Count	Phi [°]	Count	Phi [°]	Count	Phi [°]	Count	Phi [°]
No cut	310	0.15	281	0.19	342	0.62	342	0.63
Convergence cut	255	0.12	213	0.14	216	0.67	239	0.70
Convergence + antennas cuts	255	0.12	213	0.14	180	0.25	192	0.25
Convergence +antennas + zenith cuts	251	0.11	210	0.13	173	0.14	185	0.14
Convergence + antennas + zenith + z_sph cuts	**210**	**0.09**	**184**	**0.13**	**153**	**0.13**	**164**	**0.14**

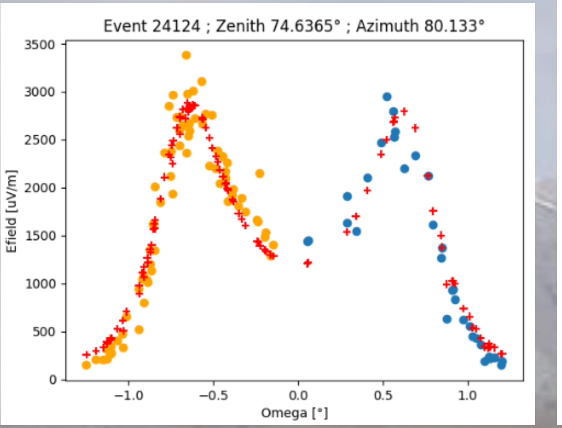
Mean angular distance with different cuts (antennas : >= 5, zenith : > 60)

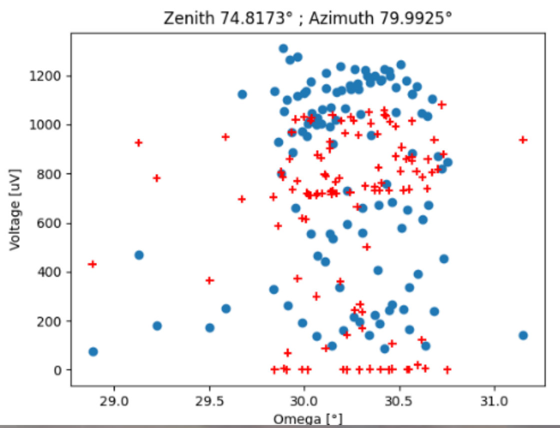
Cuts	Efield Zhaires	Voltage Zhaires NJ	Voltage Zhaires AN	Voltage Zhaires AN (with uncertainties)
Total	310	281	342	342
Convergence cut	55	68	126	103
Antenna cut	0	0	60	60
Z_sph cut	44	33	33	33
Zenith	19	16	27	27

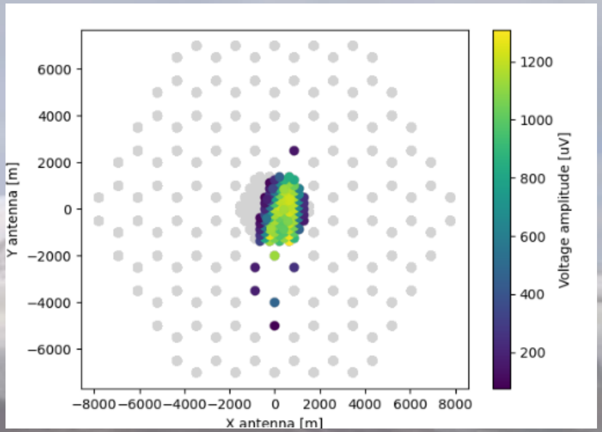
Number of events cut (antennas : >= 5, zenith : > 60)

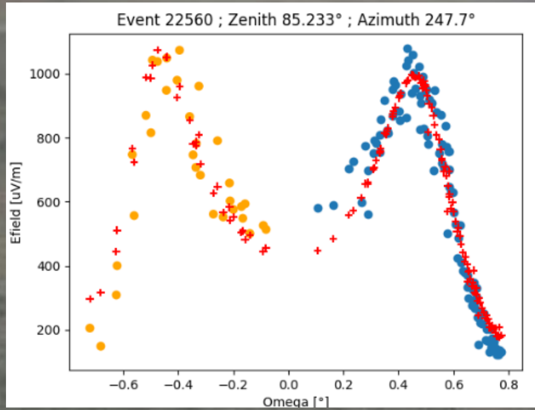


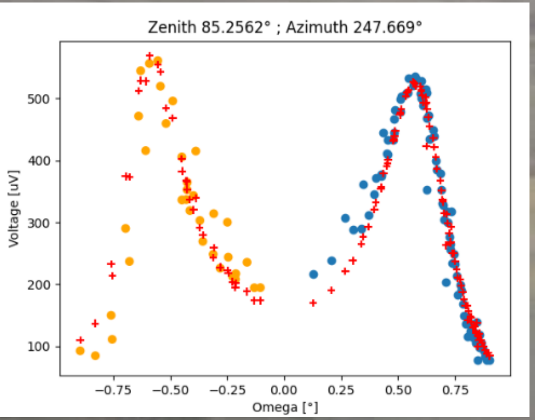
Work – Apply ADF to voltage, new data NJ

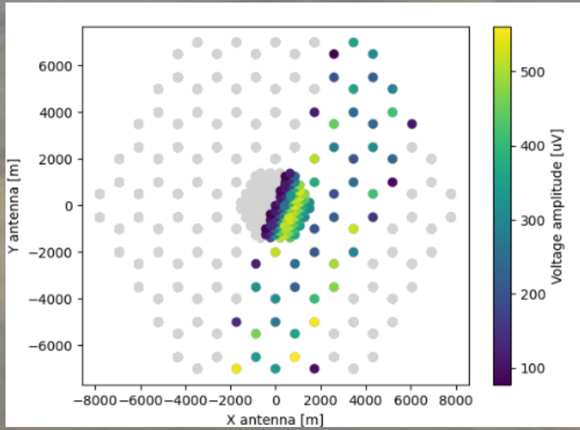








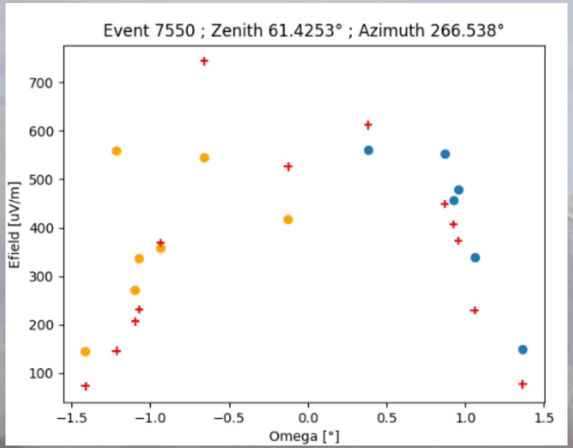


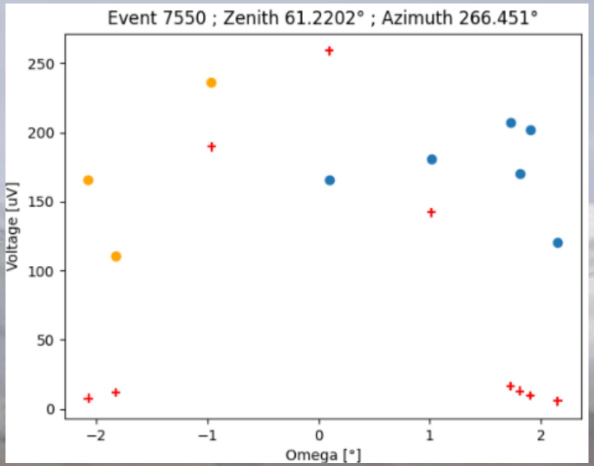


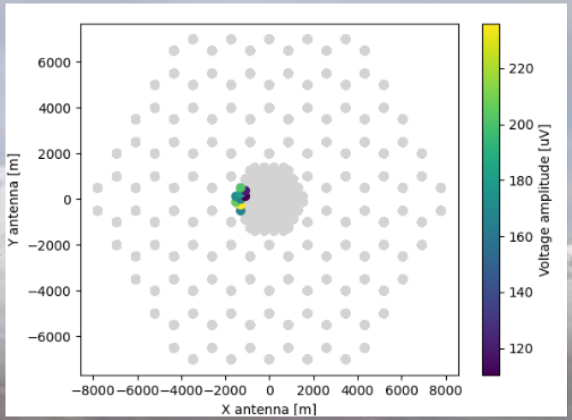
- Simulated amplitude, $\eta < 0°$
- Simulated amplitude, $\eta \geq 0°$
- Reconstructed amplitude

Horns shape : charasteristic of Cherenkov effect

Work – Apply ADF to voltage, new data AN



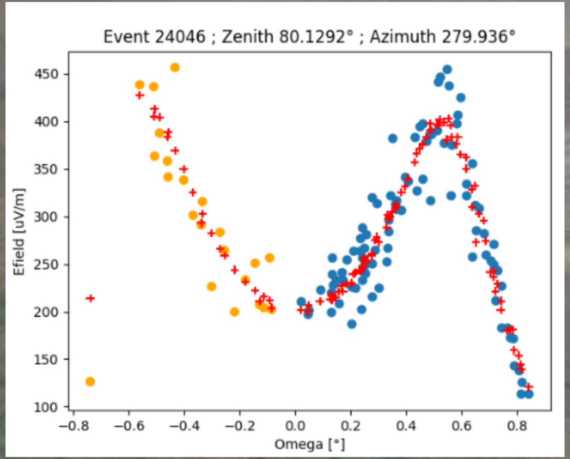


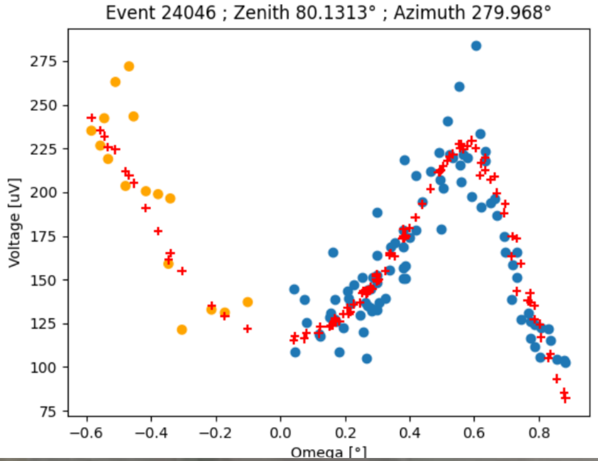


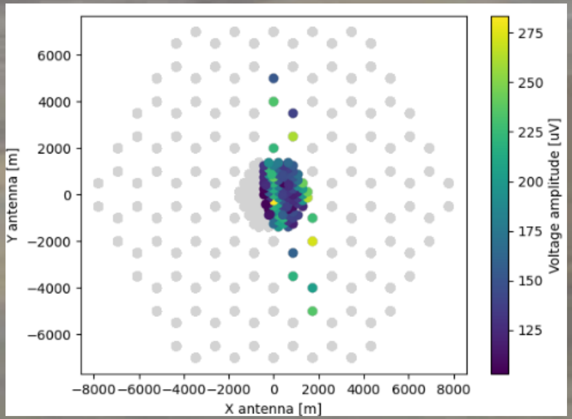
Simulated amplitude, $\eta < 0°$

Simulated amplitude, $\eta \geq 0°$

Reconstructed amplitude





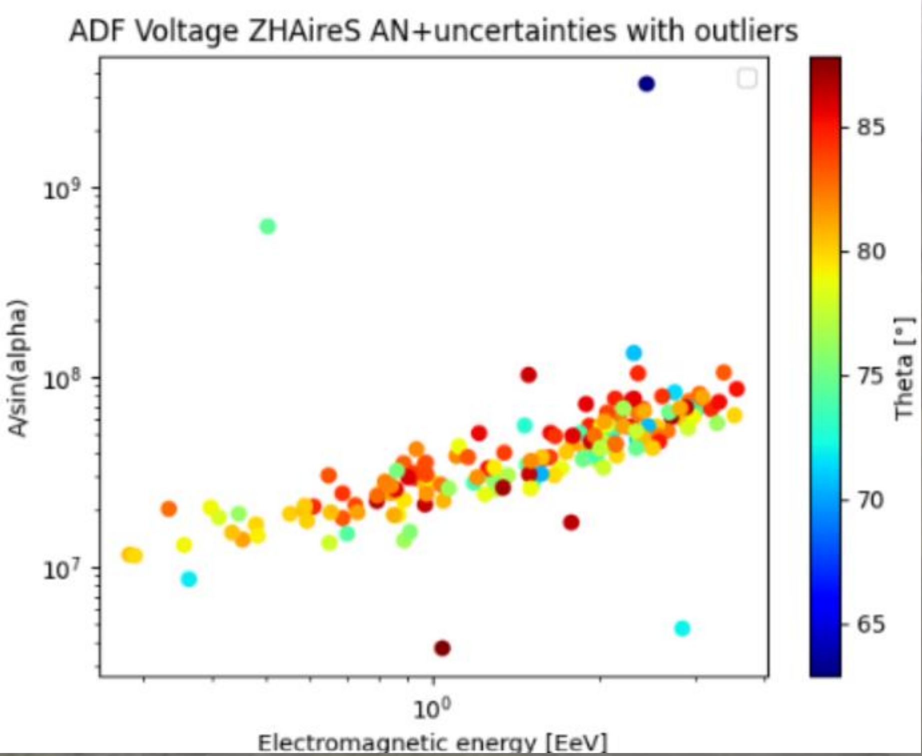


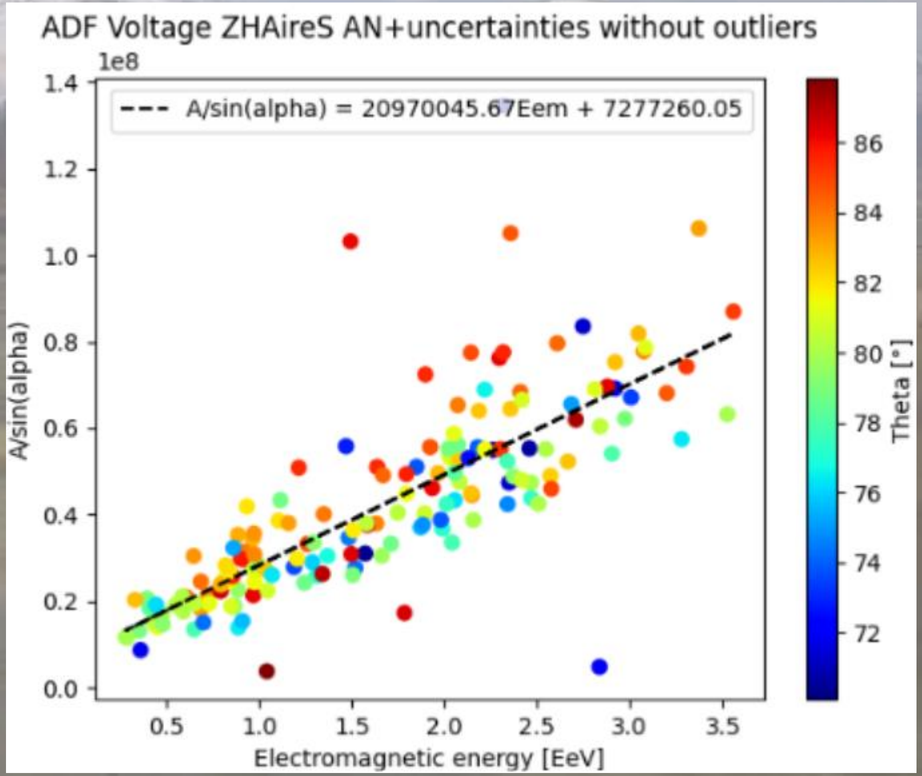
Still observed with noisy simulations !

Work – CR candidates

Method : Use calibration from simulations to estimate the energy of cosmic candidates

Fit $\frac{A}{\sin(\alpha)} = kE_{em,simu} \rightarrow E_{em,candidate}$





Perspectives

CR candidates :

Test background hypothesis with k/l fit

Grammage :

- For now, ADF uses the maximum of the Hilbert envelope of the signal
- Try using the maximum of the sharpening of the envelope instead
- Compare the obtained results and grammage

→ Work towards ICRC !

Sources

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